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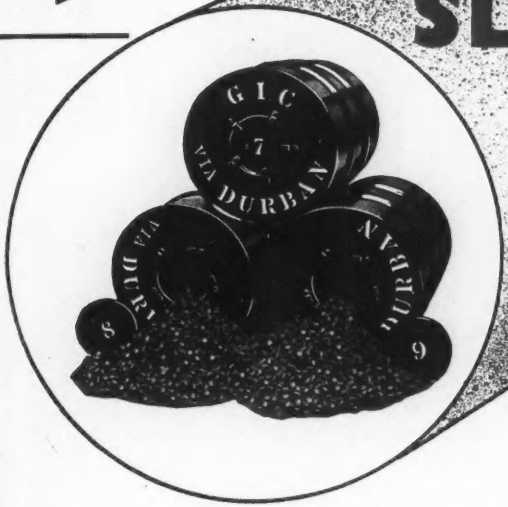

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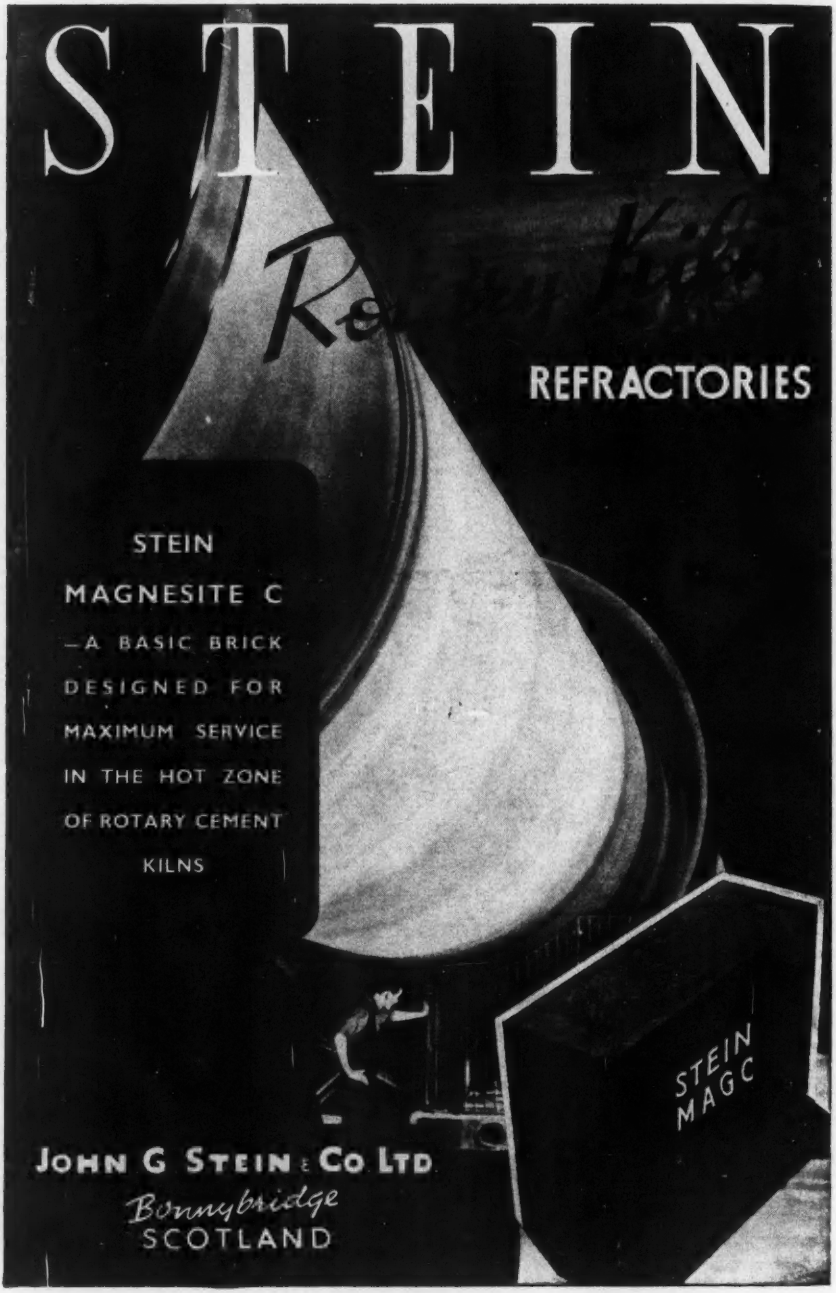
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Specification Tests for Specific Surface of Cements.

By R. W. NURSE, M.Sc., F.Inst.P.

AIR-permeability tests for the determination of the specific surface of cement have been specified in recent years in British Standard No. 12 (1947), in United States Federal Specification SS-C-158b (1946), and A.S.T.M. Standard C204-46T (1948). Although the British and U.S.A. methods are based on the same physical principles, the apparatus and procedure are different. The principles of the two methods and the differences in their application are summarised in the following, and comparative data obtained by the two procedures are given.

Principles of the Air-Permeability Tests.

It was shown empirically by Carman[1] that when a fluid is flowing through a compacted bed of powder the specific surface of the powder can be calculated from the rate of flow for a given pressure difference, the dimensions of the compacted bed, and the porosity to which the powder has been compacted.

In the British Standard method of determining the specific surface of cement as developed by Lea and Nurse[2], air is passed at a steady rate through a bed of cement 2·54 cm. in diameter and 1 cm. thick compacted to a porosity of 0·475. The pressure-drop in the bed is measured on an oil-manometer by the distance h_1 in *Fig.* 1, and the rate of flow is measured by the distance h_2 on a flowmeter consisting of another oil-manometer connected across a calibrated capillary tube. The expression for the specific surface S_w (square centimetres per gramme) is

$$\frac{14}{d(1-e)}\sqrt{\frac{e^3 A h_1}{C L h_2}}$$

where d is the density of cement (grammes per cubic centimetre); e, the fractional porosity of the bed; A, the cross-sectional area of the bed (square centimetres);

L, the thickness of the bed (centimetres) ; and C, the flowmeter constant. The porosity e is calculated from the known volume occupied by the bed and the volume of cement, thus, $e = \frac{LA - \frac{w}{d}}{LA}$, where w is the weight of cement used. For the standard apparatus of the dimensions specified,

$$S_w = K\sqrt{\frac{h_1}{h_2}}$$

where K is a constant for the apparatus and is given by

$$K = 19{\cdot}65\,\frac{1}{d}\sqrt{\frac{1}{C}}$$

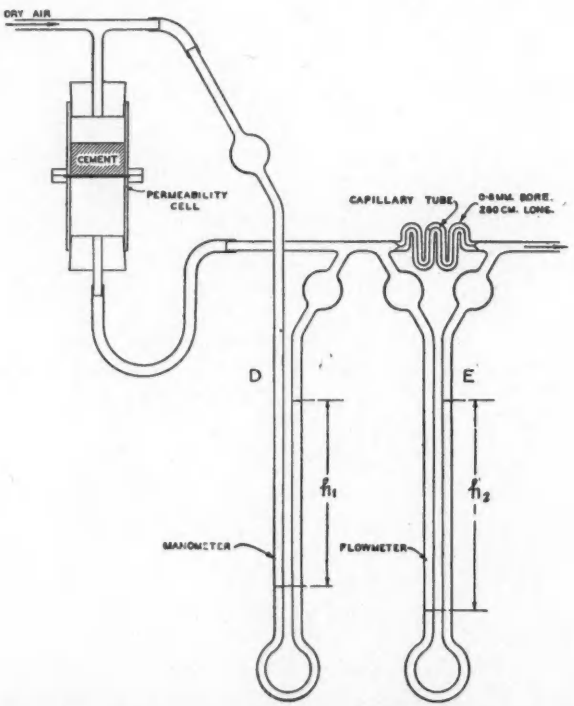

Fig. 1.—Permeability Apparatus used at the Building Research Laboratory.

For each apparatus K is tabulated for densities from 2·8 to 3·2. The flowmeter constant C is found by passing dry air through the flowmeter at a steady rate for a measured time, collecting the air over water and measuring its volume, and noting the average value of h_2. Then $C = \frac{Qn}{h_2 d_L}$, in which Q is the volume of air passed

(cubic centimetres per second) ; n, is the viscosity of air in C.G.S. units ; and d_L is the density of the liquid in the flowmeter U-tube (grammes per cubic centimetre).

The American method is based on a variation of the method of Lea and Nurse. It was first described, and its theory discussed, by Rigden[3], but it was also developed independently in the United States by Blaine[4] who devised the apparatus shown in *Fig.* 2. In this method air does not pass through the bed at a constant rate, but at a steadily diminishing rate. The oil in the manometer U-tube serves the double purpose of producing the flow of air and measuring the rate of flow. Air is withdrawn through the side tube until the oil in the manometer has risen above the uppermost timing mark ; the valve is closed and the oil-level at once begins to fall, drawing air through the bed. The time T (seconds) taken by the oil meniscus to travel between the two innermost timing marks is noted by means

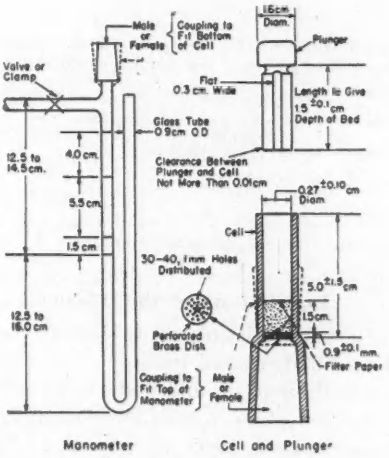

Fig. 2.—United States Permeability Apparatus.

of a stop-watch. For an apparatus of the dimensions given and a bed of standard porosity,

$$S_w = K_A\sqrt{T}$$

The constant K_A is not so easily specified from the dimensions of the apparatus as the corresponding constant K in the British Standard method, as it is affected by the diameter of the U-tube. In U.S.A. practice, K is therefore determined by using a standard sample of cement issued by the U.S. National Bureau of Standards. The standard porosity is 0·505 (±0·005) and a mercury-displacement method is employed to measure the bulk volume of the bed of cement when calibrating the apparatus. Provision is made for a correction to the specific surface if the temperature of the air varies sufficiently from the temperature at the time the apparatus was calibrated to make a significant change in the viscosity of air.

TABLE I.—COMPARATIVE SPECIFIC SURFACE OF CEMENTS.

Cement	Density (g. per cubic centimetre)	Specific Surface (sq. cm. per gramme)	
		B.S. 12(*) (actual density)	U.S. Federal Specification SS-C-158b(†) (density assumed 3·15)
RH.299	3·06	4,050	4,240
RH.480	3·09	4,050	4,040
O.240	3·13	2,640	2,630
O.477	3·07	3,460	3,560

* Average of six separate determinations at the Building Research Station.
† Average of two separate determinations at the National Bureau of Standards.

TABLE II.—SPECIFIC SURFACE OF CEMENTS DETERMINED IN THE B.S. APPARATUS IN ACCORDANCE WITH THE PROCEDURE OF THE U.S. FEDERAL SPECIFICATION.

Cement	Specific Surface (sq. cm. per gramme); $\varepsilon = 0{\cdot}505$; density assumed = 3·15 g. per cubic centimetre.	
	B.S. Apparatus*	U.S. Federal Standard Apparatus
RH.299	4,130	4,240
RH.480	4,090	4,040
O.240	2,660	2,630
O.477	3,540	3,560

*Single determinations at the National Bureau of Standards.

Limitations of the Theory.

The original theory of Carman is only approximately correct when applied to very fine powders of irregularly shaped particles. In such cases the measured specific surface varies with the porosity, and a refinement of the theory is necessary to take into account the flow of air in very fine channels [5,6]. In very precise investigations, corrections must be made for variation of atmospheric pressure and for the resistance of the filter paper used to support the bed of powder, although these corrections, which are neglected in the specification tests for cement, rarely cause a variation of more than 1 per cent. of the specific surface.

Differences Between the British and U.S.A. Test Methods.

The main differences in the test procedures which might be expected to have a significant effect on the result are :

(1).—In the U.S.A. method cements are assumed to have the same density, that is 3·15 g. per cubic centimetre. The value assumed for the density affects the calculation directly and indirectly through its effect on the calculation of the porosity.

(2).—Different standard values of porosity are specified, and are 0·475 in Great Britain and 0·505 in the U.S.A.

Other variations, which would not be expected to affect the result significantly, are the dimensions of the compacted bed of powder, the type of air flow (which is

steady in the British method and variable in the U.S.A. method), and the calibration (which is from absolute measurement in the British method and from a standard sample in the U.S.A.).

Comparative Tests.

With the co-operation of the U.S. National Bureau of Standards, four cements were tested by the British standard method and the U.S.A. Federal method. The results are given in *Table* I. It will be noted that the agreement is closer as the actual density approaches the assumed value of 3·15 g. per cubic centimetre. It would be expected that the results in accordance with the Federal specification would be slightly less than those by the British method because the test is carried out at $e = 0{\cdot}505$ compared with the British Standard value of $e = 0{\cdot}475$. It is of interest therefore to compare the results in accordance with the Federal specification with results obtained with the British Standard apparatus using the Federal Specification conditions of test, that is $e = 0{\cdot}505$ and a density of 3·15 g. per cubic centimetre. This comparison is made in *Table* II. The results show very satisfactory agreement, and it may be concluded that the British Standard apparatus may be used to estimate the specific surface S_{WF} which would be obtained by the Federal standard procedure, and vice versa, provided that suitable values of porosity and density are used. If the British standard apparatus is used,

$$S_{WF} = 7{\cdot}252 \sqrt{\frac{\overline{1}}{\overline{C}}} \sqrt{\frac{\overline{h_1}}{\overline{h_2}}}$$

The tests in accordance with the procedure of the U.S. Federal specification and with the British standard apparatus using Federal specification conditions were carried out at the National Bureau of Standards, Washington, by arrangement with Mr. R. L. Blaine. This article is published by permission of the Director of Building Research.

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Vertical Kilns in the Lime Industry.

IN recent numbers of " Revue des Materiaux de Construction," M. J. Comte, in comparing vertical and rotary lime kilns, states that rotary kilns are suitable when there is an assured market for large quantities of common lime, when the limestone contains an abundance of fines, when labour is expensive and scarce and fuel is cheap, and when heat recuperators are installed. The vertical kiln is considered to be better when it is wished to obtain a special product in small quantities, and when labour is cheap and fuel dear. Generally the cost of a rotary kiln is double that of a vertical kiln, but the operating costs may be 15 per cent. to 20 per cent. less.

Portland Cement Specifications of the World.

SINCE publication in this journal for May and July, 1949, of tables giving comparisons of the specifications for Portland cement in various countries, so many revisions have been made to the standards that we give, in the pages following, up-to-date tables of the requirements for strength (in pounds per square inch; *Table* III, pages 23 to 25), and chemical composition (*Table* I, pages 26 to 29). The strengths in kilogrammes per square centimetre can be derived from the strengths in pounds per square inch. The requirements of setting time, soundness, fineness, and preparation of specimens are not given as these are not greatly different from the data given in the tables published previously; variations have been given in recent numbers of this journal. Countries the standards of which were revised in 1949 and 1950 include Belgium, France, Poland, and Roumania. The revised tables include the Federal standards as well as the A.S.T.M. standards (1949) of the United States.

Proposals for an International Specification.

The possibility of having an international standard for Portland cements has been considered recently in foreign journals, for example in "Cemento Hormigon," for February, 1951, in which are described the proposals of some European countries to set up a committee for the purpose. The British Standards Institution is collaborating in this matter with the International Standards Organisation.

Some proposals are given in "Zement, Kalk, und Gips," by E. Plassmann and W. Wittekindt, who suggest that for the present an international specification should be restricted to testing Portland cement of two qualities, namely ordinary Portland cement and Portland cement of high strength and especially rapid-hardening Portland cement. The SO_3-content should not exceed 3 per cent.; MgO, 5 per cent.; insoluble residue, 1 per cent. (or an absolute maximum of 2 per cent.); and loss on ignition, 3 per cent. to 4 per cent. No additions, other than gypsum and water, should be permitted. The specific gravity need not be specified. In the case of ordinary cement the residue on a sieve having 4900 meshes per square centimetre (or B.S. sieve No. 170 or A.S.T.M. sieve No. 170) should not exceed 10 per cent. The specific surface of high-strength cement should be specified. The setting test should be made by the Vicat apparatus, and the initial set should occur in not less than 45 minutes and the final set in not more than twelve hours. The consistency for this test should be such that the needle (10 mm. diameter, weight 300 g.) sinks 5 mm. to 7 mm. in half a minute. The cold-pat test and either the boiling test or the Le Chatelier test should be made for soundness, but for cements containing more than 3 per cent. of MgO the autoclave test (A.S.T.M. procedure) should be made. A standard sand should be specified for the strength tests, the results of which should be in accordance with reliable European and American cements. The authors recommend that the strengths of high-strength cement should be in accordance with British Standard No. 12 for rapid-hardening Portland cement, or Type III (A.S.T.M.), or German Z 425, and that all properties should be expressed in the metric system.

TABLE III.—STRENGTH OF PORTLAND CEMENT (LB. PER SQUARE INCH).

NOTES.—For dates of Standards see Table I.

(1) The following countries, which adopt the standards of other countries, are omitted: Egypt (O., as Britain, 1947); Iceland (O., as Denmark, 1933); India (O., as Britain, 1947); Jamaica (O., as Britain, 1947); Paraguay (as Argentina); Peru (as United States); South Africa (O. and R.H., as Britain, 1947); Austria (as Germany); Luxembourg (as Belgium); New Zealand (as Britain).

(2) Abbreviations of types of cement: H.S., high strength; L.H., low heat; L.S., low strength; M.L.H., moderate low heat; M.S.R., moderate sulphate resistant; O., ordinary; R.H., rapid hardening; S.R., sulphate resistant; S.S., superior high strength.

(3) Strengths are measured on 3 sand : 1 cement mortar except where indicated otherwise. Tests marked* are optional. c.s. = combined wet and dry storage.

Country (see Note 1)	Type of Cement (see Note 2)	Tensile Strength Age of specimen in days						Bending Strength Age of specimen in days				Compressive Strength Age of specimen in days					
		1	2	3	7	28	28(c.s.)	1	3	7	28	1	2	3	7	28	28 (c.s.)
Argentina	O.	—	—	—	235	398	—	—	—	—	—	—	—	—	3270	4620	—
	R.H.	285	356	427	498	—	712	—	—	—	—	3200	4980	5690	6400	—	8540
Australia	O.	—	—	—	—	—	—	—	—	—	—	—	—	2500	3500	4500	—
	R.H.	—	—	—	—	—	—	—	—	—	—	—	—	4000	5500	6500	—
Belgium	O.	—	—	256	327	384	—	—	—	—	—	—	—	2845	4266	5690	—
	H.S.	—	—	327	384	427		—	—	—	—	—	—	4266	5690	7110	—
	R.H.	285	—	384	427	455	—	—	—	—	—	3200	—	5690	7110	8178	—
Brazil	O.	—	—	—	—	—	—	—	—	—	—	—	—	1140	2133	3556	—
	R.H.	—	—	—	—	—	—	—	—	—	—	1565	—	3129	4409	—	—
Bulgaria	O.	—	—	—	256	356	427	—	—	—	—	—	—	—	2845	4267	5690
	R.H.	—	—	356	—	427	569	—	—	—	—	—	—	3560	—	5690	7112
Britain	O.	—	—	300	375	—	—	—	—	—	—	—	—	1600	2500	—	—
	R.H.	300	—	450	—	—	—	—	—	—	—	1600	—	3500	—	—	—
	L.H.	—	—	—	—	—	—	—	—	—	—	—	—	1000	1600	3750	—
Canada	O.	—	—	200	275	350	—	—	—	—	—	—	—	—	—	—	—
	R.H.	275	—	375	—	—	—	—	—	—	—	—	—	—	—	—	—
	S.R.	—	—	150	250	350	—	—	—	—	—	—	—	—	—	—	—
Chile	O.	—	—	—	356	427	—	—	—	—	—	—	—	—	3556	4978	—
	H.S.	—	—	356	427	540	—	—	—	—	—	—	—	3556	4978	6400	—
China	O.	—	—	—	256	356	—	—	—	—	—	—	—	—	2560	3910	—
	H.S.	—	—	356	—	427	—	—	—	—	—	—	—	3556	—	5690	—
Czechoslovakia	O.	—	—	—	256	356	427	—	—	—	—	—	—	—	2845	3910	4978
	R.H.	—	—	356	398	427	569	—	—	—	—	—	—	3910	5334	6045	7112

TABLE III.—STRENGTH OF PORTLAND CEMENT (LB. PER SQUARE INCH). (*Cont.*)

NOTES.—For dates of Standards see Table I.

(1) The following countries, which adopt the standards of other countries, are omitted: Egypt (O., as Britain, 1947); Iceland (O., as Denmark, 1933); India (O., as Britain, 1947); Jamaica (O., as Britain, 1947); Paraguay (as Argentina); Peru (as United States); South Africa (O. and R.H., as Britain, 1947).; Austria (as Germany); Luxembourg (as Belgium); New Zealand (as Britain).

(2) Abbreviations of types of cement: H.S., high strength; L.H., low heat; L.S. low strength; M.L.H., moderate low heat; M.S.R., moderate sulphate resistant; O., ordinary; R.H., rapid hardening; S.R., sulphate resistant.; S.S., superior high strength.

(3) Strengths are measured on 3 sand : 1 cement mortar except where indicated otherwise. Tests marked * are optional. c.s. = combined wet and dry storage.

Country (see Note 1)	Type of Cement (see Note 2)	Tensile Strength Age of specimen in days						Bending Strength Age of specimen in days				Compressive Strength Age of specimen in days					
		1	2	3	7	28	28(c.s.)	1	3	7	28	1	2	3	7	28	28 (c.s.)
Denmark	O.	—	—	—	284*	356*	427*	—	—	—	—	—	—	—	4551	5690	6400
	R.H.	—	—	284	284	356	427	—	—	—	—	—	—	4267	4551	5690	6400
Eire	O.	—	—	330	430	—	—	—	—	—	—	—	—	—	—	—	—
	R.H.	300	—	455	—	—	—	—	—	—	—	—	—	—	—	—	—
Finland	O.	—	—	—	—	—	—	—	427*	569	853	—	—	2133*	3200	4978	—
	R.H.	—	—	—	—	—	—	356*	712	853*	996	1422*	—	4267	5334*	6400	—
	L.H.	—	—	—	—	—	—	—	—	427*	712	—	—	—	1778*	3556	90 days 4978
France	O.	—	—	—	284*	356*	—	—	—	—	—	—	—	—	2276	3556	—
	R.H.	—	256	—	356	427	—	—	—	—	—	—	2276	—	4480	5689	—
	H.S.	—	—	—	284	356	—	—	—	—	—	—	—	—	3058	4880	—
	S.S.	—	—	—	427	498	—	—	—	—	—	—	—	—	5049	7112	—
Germany	L.S.	—	—	—	—	—	—	—	—	356*	712	—	—	—	1565*	3200	—
	O.	—	—	—	—	—	—	—	427*	569	853	—	—	2133*	3200	4622	—
	R.H.	—	—	—	—	—	—	356*	711	853*	996	1422*	—	4267	5120*	6045	—
Hungary	O.	—	—	—	213	313	—	—	—	—	—	—	—	—	2844	3982	—
	R.H.	—	284	—	384	427	—	—	—	—	—	—	3555	—	5688	7110	—
Italy	O.	—	—	—	370	455	—	—	—	—	—	—	—	—	5405	7112	—
	R.H.	—	—	299	442	526	—	—	—	—	—	—	—	4125	7112	9672	—
Japan‡‡	O.	—	—	—	—	—	—	—	142	284	427	—	—	498	996	2418	—
	R.H.	—	—	—	—	—	—	—	284	498	782	—	—	1138	2276	3556	—
Mexico‡	O.	—	—	142	270	341	—	—	—	—	—	—	—	711	1422	2133	—
	R.H.	270	—	370	—	—	—	—	—	—	—	711	—	2133	—	—	—
	M.S.R. and M.L.H.	—	—	128	242	327	—	—	—	—	—	—	—	498	1422	2133	—
	L.H.	—	—	—	185	299	—	—	—	—	—	—	—	—	711	1778	—
	S.R.	—	—	—	185	299	—	—	—	—	—	—	—	—	924	2133	—

Netherlands	O.	—	—	—	256*	370	—	—	—	—	—	—	—	—	2845*	4267	—	
	R.H.	—	—	327	370	455	—	—	—	—	—	—	—	3555	4980	6045	—	
Norway	O.	—	—	228*	312	384	—	—	—	—	—	—	—	2560*	3555	4980	—	
	R.H.	—	256	—	384	427	—	—	—	—	—	—	3555	—	5330	6400	—	
Palestine	O.	—	—	284	356	—	—	—	—	—	—	—	—	1565	2489	—	—	
	R.H.	284	—	427	—	—	—	—	—	—	—	1565	—	3485	—	—	—	
Poland†	O.	—	—	—	—	—	—	—	—	427	711	—	—	—	1849	3555	—	
	H.S.	—	—	—	—	—	—	—	498	640	924	—	—	2560	3983	5689	—	
Portugal	L.S.	—	—	—	171	228	—	—	—	—	—	—	—	—	2133	3414	—	
	O.	—	—	—	242	299	—	—	—	—	—	—	—	—	2845	4267	—	
	L.H.	—	—	—	242	299	—	—	—	—	—	—	—	—	2845	4267	—	
	S.R.	—	—	—	242	299	—	—	—	—	—	—	—	—	2845	4267	—	
Roumania	O.	—	—	—	284	356	—	—	—	—	—	—	—	—	2845	4267	—	
	H.S.	—	—	356	427	484	—	—	—	—	—	—	—	3698	5405	7112	—	
	R.H.	—	—	284	356	398	—	—	—	—	—	—	—	2845	3983	5689	—	
Russia	O.	—	—	—	172	228	—	—	—	—	—	—	—	—	1890	—	—	
	R.H.	—	—	312	384	455	—	—	—	—	—	—	—	4697	7110	8540	—	
Spain††	O.	—	—	—	270	335	—	—	—	—	—	—	—	—	2708	3980	—	
	R.H.	—	—	356	427	540	—	—	—	—	—	—	—	3550	4977	6399	—	
Sweden	O.	—	—	—	—	—	—	—	—	640	924	—	—	—	3556	5689	—	
	R.H.	—	—	—	—	—	—	427*	853	924*	996	2133*	—	4622	5689*	7112	—	
	L.H.	—	—	—	—	—	—	—	—	427*	711	—	—	—	2133	3911	90 days	
																	5689	
Switzerland	O.	—	—	—	—	—	—	—	—	498	640	—	—	—	2560	3911	—	
	H.S.	—	—	—	—	—	—	—	569	711	853	—	—	3556	4836	5974	—	
Turkey	O.	—	—	—	313	384	455	—	—	—	—	—	—	—	4267	4978	5689	
	R.H.	—	—	384	—	484	597	—	—	—	—	—	—	4978	—	6045	7467	
U.S.A.**	O.	—	—	150	275	350	—	—	—	—	—	—	—	900	1800	3000	—	
	(M.S.R.,-M.L.H.)	—	—	125	250	325	—	—	—	—	—	—	—	750	1500	3000	—	
	R.H.	275	—	375	—	—	—	—	—	—	—	1250	—	2500	—	—	—	
	L.H.	—	—	—	175	300	—	—	—	—	—	—	—	—	800	2000	—	
	S.R.	—	—	—	250	325	—	—	—	—	—	—	—	—	1500	3000	—	
Uruguay	O.	—	—	—	—	—	—	—	—	—	—	—	—	—	2133	—	—	
	R.H.	—	—	—	—	—	—	—	—	—	—	1565	—	—	4409	—	—	
Venezuela	O.	—	—	—	284	356	—	—	—	—	—	—	—	—	—	—	—	
Yugoslavia	O.	—	—	—	228	—	398	—	—	—	—	—	—	—	2845	3982	4551	
	H.S.	—	284	—	398	—	—	—	—	—	—	—	3413	—	5689	—	—	

† 2 (coarse) : 1 (fine) : 1 mortar. ‡ 2·77 : 1 mortar. ** 2·75 : 1 mortar; Federal specification does not require tensile test.
†† 600 g. cement : 1 litre sand. ‡‡ 2 : 1 mortar.

TABLE I.—CHEMICAL COMPOSITION OF PORTLAND CEMENT.

NOTES.

(1) The following countries, which adopt the standards of other countries, are omitted: Egypt (O., as Britain, 1947); Iceland (O., as Denmark, 1933); India (O., as Britain, 1947); Jamaica (O., as Britain, 1947); Paraguay (as Argentina); Peru (as United States); South Africa (O. and R.H., as Britain, 1947); Austria (as Germany); Luxembourg (as Belgium); New Zealand (as Britain).

(2) Abbreviations of types of cement: H.S., high strength; L.H., low heat; L.S., low strength; M.L.H., moderate low heat; M.S.R., moderate sulphate resistant; O., ordinary; R.H., rapid hardening; S.R., sulphate resistant; S.S., superior high strength.

(3) Chemical abbreviations: C = CaO; S = SiO_2; A = Al_2O_3; F = Fe_2O_3; Mn = Mn_2O_3; R = R_2O_3; C_3A = $3CaO.Al_2O_3$, etc.

(4) Permitted tolerances are given in brackets.

(5) Permitted additions exclude water and $CaSO_4$ (added to regulate the setting time) unless specifically stated otherwise.

Country and date of Standard (See Note 1)	Type of Cement (See Note 2)	Chemical Ratios based on percentages (See Note 3)	Maximum Percentages (See Note 4)					Remarks
			MgO	SO_3	Insoluble residue	Loss on ignition	Permitted additions (See Note 5)	
Argentina (1947)	O. R.H.	$\frac{C}{S+A+F} \not< 1{\cdot}7$	4·0	2·5	1·0	3·0	None	—
Australia (1948)	O. R.H.	—	4·0 (+ 0·25)	2·75 (+ 0·10)	2·0 (+ 0·15)	3·0 (+ 0·15)	None	—
Belgium (1949)	O. H.S. R.H.	—	3·0	3·0	—	—	None	Specific gravity $\not<$: 3·05
Brazil (O.—1937 R.H.—1940)	O.	—	6·0 (+ 0·40)	2·5 (+ 0·15)	0·85 (+ 0·15)	4·0 (+ 0·30)	None	—
	R.H.	—	5·0 (+ 0·30)	2·5 (+ 0·15)	0·85 (+ 0·15)	4·0 (+ 0·30)	1·0	—
Britain (1947)	O. R.H.	$\frac{C-0{\cdot}7\,SO_3}{2{\cdot}8S+1{\cdot}2A+0{\cdot}65F} \not< 0{\cdot}66 \not> 1{\cdot}02$ $\frac{A}{F} \not< 0{\cdot}66$	4·0	2·75	1·0	3·0 or 4·0 in hot climates	None	—
	L.H.	$\frac{C-0{\cdot}7SO_3}{2{\cdot}4S+1{\cdot}2A+0{\cdot}65F} \not> 1{\cdot}0$ $\frac{C-0{\cdot}7SO_3}{1{\cdot}9S+1{\cdot}2A+0{\cdot}65F} \not< 1{\cdot}0$ $\frac{A}{F} \not< 0{\cdot}66$	4·0	2·75	1·0	3·0	None	Heat of hydration (max.): 7 days: 65 calories per gr. 28 " 75 " " "

Bulgaria (1941)	O. R.H.	$\frac{C}{S+A+F} \leqslant 1.7$	5·0	3·0	—	5·0	3·0	—
Canada (O., R.H.—1940. S.R.—1942)	O.	—	4·0 (+ 0·40)	2·0 (+ 0·20)	0·75 (+ 0·15)	3·0 (+ 0·25)	None	
	R.H.	—	4·0 (+0·40)	2·5 (+ 0·20)	0·75 (+ 0·15)	3·0 (+ 0·25)	None	
	S.R.	$\frac{S}{A+F} \leqslant 2.8$ $\frac{F}{A} \geqslant 1.3$	3·0 (+ 0·30)	2·0 (+ 0·20)	0·5 (+ 0·10)	3·0 (+ 0·30)	None	A $\geqslant$ 4 (+ 0·40) per cent. $C_3A \geqslant 4$ (+ 0·40) per cent.
Chile (1941)	O. H.S.	$\frac{C-0.7SO_3}{S+A+F+Mn} \leqslant 1.7$	2·0	2·0	1·5	3·0	None	Specific gravity $\leqslant$ 3·05. For marine work $\frac{S}{A+F} \geqslant 2.2$
China (1934)	O.	—	4·0	2·75	1·0	4·0	—	—
Czechoslovakia (1947)	O. R.H.	—	6·0	3·0	—	—	—	—
Denmark (O.—1933 R.H.—1942)	O. R.H.	$\frac{C}{S+A+F} \leqslant 1.8$	3·0 3·0	— 3·0 (+ 0·2)	—	—	3* 6*	*Including gypsum
Eire (1949)	O. R.H.	$\frac{C-0.7SO_3}{2.8S+1.2A+0.65F} \leqslant 0.66 \geqslant 1.00$ $\frac{F}{A} \geqslant 1.5$	4·0	2·75	1·0	4·0	None	—
Finland (1945)	O.	—	5·0	—	—	—	15	—
	R.H.	—	5·0	—	—	—	3	—
	L.H.	—	5·0	—	—	—	15	Heat evolved (1 : 6 mixture) : 3 days : 55 cal. per g. (max.) 7 ,, 65 ,, ,,
France (1950)	O. H.S.; S.S. R.H.	—	5·0	3·0	3·0	4·0	3·0	
Germany (1942)	L.S. O. R.H.	—	5·0	3·0	—	5·0	1·0	—
Hungary (1935)	O. R.H.	$\frac{C}{S+A+F+Mn} \leqslant 1.8$	5·0	3·0	2·0	5·0	—	Specific gravity $\leqslant$ 3·0
Italy (1939)	O. H.S.	$\frac{C}{S+R} \leqslant 1.7$	3·0	2·5	1·5	5·0	None	—
Japan (1941)	O. R.H.	—	3·0	2·0	—	4·0	None	Specific gravity $\leqslant$ 3·05

TABLE I.—CHEMICAL COMPOSITION OF PORTLAND CEMENT. (*Cont.*)

NOTES.

(1) The following countries, which adopt the standards of other countries, are omitted: Egypt (O., as Britain, 1947); Iceland (O., as Denmark, 1933); India (O., as Britain, 1947); Jamaica (O., as Britain, 1947); Paraguay (as Argentina); Peru (as United States); South Africa (O. and R.H., as Britain, 1947); Austria (as Germany); Luxembourg (as Belgium); New Zealand (as Britain).

(2) Abbreviations of types of cement: H.S., high strength; L.H., low heat; L.S., low strength; M.L.H., moderate low heat; M.S.R., moderate sulphate resistant; O., ordinary; R.H., rapid hardening; S.R., sulphate resistant.

(3) Chemical abbreviations: $C = CaO$; $S = SiO_2$; $A = Al_2O_3$; $F = Fe_2O_3$; $Mn = Mn_2O_3$; $R = R_2O_3$; $C_3A = 3CaO.Al_2O_3$, etc.

(4) Permitted tolerances are given in brackets.

(5) Permitted additions exclude water and $CaSO_4$ (added to regulate the setting time) unless specifically stated otherwise.

Country and date of Standard (See Note 1)	Type of Cement (See Note 2)	Chemical Ratios based on percentages (See Note 3)	Maximum Percentages (see Note 4)					Remarks
			MgO	SO_3	Insoluble residue	Loss on ignition	Permitted additions (See Note 5)	
Mexico (1943)	O.	—	4·0	2·0	0·75	3·0	1·0	Alkalis $\not>$ 1·2 per cent.
	R.H.	—	4·0	2·5	0·75	3·0	1·0	Alkalis $\not>$ 1·2 per cent. C_3A $\not>$ 5 per cent.
	M.L.H. M.S.R.	$\frac{A}{F}$ $\not<$ 0·7 $\not>$ 2·0	4·0	2·0	0·75	3·0	1·0	S $\not<$ 21 per cent.; A $\not>$ 6 per cent. C_3A $\not>$ 8 per cent. F $\not<$ 6 per cent. C_3S $\not<$ 50 per cent. Alkalis $\not>$ 0·9 per cent.
	L.H.	$\frac{A}{F}$ $\not<$ 0·7 $\not>$ 2·0	4·0	2·0	0·75	2·3	1·0	Alkalis $\not>$ 0·8 per cent. S $\not<$ 21 per cent.; F $\not>$ 6 per cent. C_3S $\not<$ 30 per cent.; C_3A $\not>$ 7 per cent. C_3S $\not<$ 40 per cent.
	S.R.	$\frac{A}{F}$ $\not<$ 0·7 $\not>$ 2·0	4·0	2·0	0·75	2·5	1·0	S $\not<$ 24 per cent.; A $\not>$ 4 per cent. F $\not>$ 4 per cent.; C_3A $\not>$ 5 per cent. Alkalis $\not>$ 0·9 per cent.
Netherlands (1933)	O. R.H.	$\frac{C}{S+A+F}$ $\not<$ 1·7	5·0	2·5	3·0	—	None	—
Norway (1934)	O. R.H.	$\frac{C}{S+A+F+Mn}$ $\not<$ 1·7 $\not>$ 2·4	4·0	2·75	1·5	4·0	None	Specific gravity $\not<$ 3·05
Palestine (1947)	O. R.H.	$\frac{C-0{\cdot}7SO_3}{2{\cdot}8S+1{\cdot}2A+0{\cdot}65F}$ $\not<$ 0·67 $\not>$ 1·0 $\frac{F}{A}$ $\not>$ 1·5	4·0	2·75	1·0	4·0	None	—
Poland (1950)	O.	—	5·0	3·0	—	5·0	None	—
	H.S.	—	5·0	3·0	1·5	3·0	—	

Portugal (L.S., O.—1930. L.H. —1946. S.R. —1932)	L.S.	—	4·0 (+ 0·40)	2·5 (+ 0·10)	1·5 (+ 0.15)	4·0 (+ 0.30)	None	Specific gravity ⩽ 3·05
	O.	—						F ⩾ 6·5 per cent. ; C_3S ⩾ 35 per cent. C_3A ⩾ 7 per cent. ; C_2S ⩾ 40 per cent.
	L.H.	—	5·0	2·0	0·75	2·3	—	
	S.R.	$\frac{C}{S+A+F}$ ⩽ 1·8 ⩽ 2·2	3·0	2·0	1·5 (+ 0·15)	4·0 (+ 0·3)	None	Specific gravity ⩽ 3·05 A ⩾ 8 per cent.
Roumania (1949)	O.	—	5·0	3·0	5·0	5·0	††	††Substances with hydraulic properties permitted in O. if insoluble residue not exceeded
	H.S.		2·5	2·5	1·0	3·0	1·0	
	R.H.		2·5	2·5	1·0	3·0	1·0	
Russia (1936)	O.	—	4·5	2·5	—	4·0	10·0*	*Including gypsum Specific gravity ⩽ 3·0 ⩾ 3·2
	R.H.							
Spain (1936)	O.	$\frac{C}{S+A+F}$ ⩾ 2·3 ⩽ 1·8 $\frac{S}{A}$ ⩽ 2·5	$MgO+SO_3$ ⩾ 6·5		1·5	4·0	‡ 6·0*	Sulphur ⩾ 1·25 per cent. Specific gravity ⩽ 3·05 ‡Including gypsum ⩾ 3 per cent. plus ⩾ 2 per cent. water
	R.H.							
Sweden (1943)	O.	—	—	—	—	—	3·0	—
	R.H.							
	L.H.	—	—	—	—	—	3·0	Heat evolved (1 : 6 mixture) 3 days : 55 cals. per g. 7 days : 65 cals. per g.
Switzerland (1945)	O.	$\frac{C}{S+R}$ ⩾ 2·0	4·0 (+ 1·2)	2·5 (+ 0·75)	5·0 (+ 1·5)	—	10·0*	*Including gypsum Specific gravity ⩽ 3·0 ⩾ 3·2
	H.S.							
Turkey (1937)	O.	$\frac{C}{S+A+F}$ ⩽ 2·0	4·0	2·5	0·85	3·0	3·0*	*Including gypsum Specific gravity ⩽ 3·05
	R.H.							
United States of America (A.S.T.M. 1949. Data thus [ ] are for Federal Specification, 1946, if different.)	Type I (O.)	—	5·0	2·0†	0·75	3·0	1·0	†2·5 if C_3A > 8 per cent. [A ⩾ 7·5 ; F ⩾ 6 ; C_3A ⩾ 15 per cent.]
	Type II (M.S.R., M.L.H.)	—	5·0	2·0	0·75	3·0	1·0	S ⩽ 21 per cent. ; A ⩾ 6 per cent. F ⩾ 6 per cent. ; C_3S ⩾ 50 per cent. C_3A ⩾ 8 per cent.
	Type III (R.H.)	—	5·0	2·5†	0·75	3·0	1·0	C_3A ⩾ 15 per cent. [A ⩾ 7·5 ; F ⩾ 6 per cent.] †3·0 if C_3A > 8 per cent.
	Type IV (L.H.)	—	5·0	2·0 [2·25]	0·75	2·3 [2·5]	1·0	F ⩾ 6·5 per cent. ; C_3S ⩾ 35 per cent. C_3S ⩽ 40 per cent. ; C_3A ⩾ 7 per cent. [S ⩽ 22 ; A ⩾ 6 per cent.]
	Type V (S.R.)	—	4·0	2·0	0·75	3·0	1·0	$C_4AF + 2(C_3A)$ ⩾ 20 per cent. [S ⩽ 23 per cent.] C_3S ⩾ 50 per cent. ; C_3A ⩾ 5 per cent.
Uruguay (1945)	O.	—	4·0	2·5	0·85	3·0	1·0	—
	R.H.	—	4·0	2·5	0·85	3·0	1·0	C_3A ⩾ 15 per cent.
Venezuela (1941)	O.	—	5·0	2·0	0·75	3·0	—	—
Yugoslavia (1948)	O.	$\frac{C}{S+R}$ ⩾ 1·7	5·0	3·0	—	—	—	—
	H.S.							

Mechanical Determination of the Setting Time of Portland Cement.

AN automatic machine, which determines the setting time of samples of Portland cement, and thereby relieves the tester of having to examine the samples from time to time, is described by Mr. O. J. Glantz and Mr. L. E. Halsted in the " A.S.T.M. Bulletin " for December, 1950.

The machine, which is called a spissograph, records graphically the thickening and hardening of cement pastes and mortars, and the setting times of four samples can be determined at the same time. The samples are placed in cylindrical moulds, and needles similar to those on the Vicat apparatus are lowered mechanically. The depth of penetration of each needle is recorded on a chart mounted on a drum. A small motor rotates the shaft on which are fixed cams which rotate the moulds so that each penetration is in a different part of the paste, and which lower the needle on to each sample at intervals of ten minutes. The cams also rotate the recording drum a definite distance so that each value is properly recorded. The samples are enclosed in a watertight compartment and automatically controlled air jets keep the humidity at about 100 per cent. Automatic wipers which keep the needles clean are incorporated and a separate motor and clutch allow the needles to penetrate each sample at intervals of one minute if required.

As a result of tests it is concluded by the authors that the spissograph is a practical instrument for mechanically determining setting time. Results agree well with the Vicat test for initial set, although they give lower results for final sets. Agreement with the Gillmore test is reasonably good for initial set, but lower for final set. The spissograph eliminates much of the human factor in the setting-time test, as well as the time required for making frequent checks. It provides, conveniently, results for slow-setting cements which require more than the usual working day, and a permanent record is obtained.

Detailed drawings of the spissograph are available on request to the U.S. Bureau of Reclamation, Denver, Colo., U.S.A.

The Cement Industry Abroad.

PORTUGUESE TERRITORY.—It is reported in " Cemento Hormigon " that a new cement works, the property of Companhia de Cimentos de Mozambique, has been built near Beira, Mozambique, and can produce 60,000 tons of Portland cement annually.

The Companhia de Cimentos de Angola is building a works near Lobito which will have an initial capacity of 90,000 tons and is planned for double this amount. The kiln will be about 350 ft. long.

CEMENT PRODUCTION IN SPAIN.—The production of cement in Spain in 1950 was about 13 per cent. greater than in 1949. The production was 1,970,000 tons of clinker (1,740,000 tons in 1949), 1,910,000 tons of Portland cement (1,670,000 tons in 1949), and 167,000 tons of other types of artificial cements, which is about the same as in 1949.

Fuel Consumption in Cement Works.

THE utilisation and economy of fuels in rotary and vertical kilns has received much attention in Italy since the war, and in the following abstracts of three articles on the subject are given.

In "Industria Italiana del Cemento," Professor L. Santarelli considers the general problem of the use of solid fuel in rotary kilns from the point of view of the fineness, the content of volatile matter, and the ash content (and composition of the ash) of coal. The rate of combustion of the air-coal mixture, it is stated, is proportional to the specific surface of the fuel. The high degree of fineness necessary to obtain rapid combustion also reduces the size of the particles of ash and consequently reduces the amount of ash deposited in crevices in the lining of the kiln, and results in the ash coming in contact with the material at the front end of the kiln. The deposition of the ashes in the coolest part of the kiln avoids the formation, especially if the ashes are argillaceous, of incrustations and rings on the lining, which obstruct the regular forward movement of the raw material and clinker. It is stated that the fineness generally necessary to ensure regular operation of a kiln is a residue to 10 per cent. to 15 per cent. on a sieve having 4,900 meshes per square centimetre. The optimum proportion of volatile matter is between 15 per cent. and 25 per cent.

The percentage of ash and the composition of the ash influence the hydraulic modulus and other properties of the clinker, and adjustment of the composition of the raw materials is advisable. The author quotes as an example coal having an ash content of 20 per cent. and a consumption of about 30 per cent. of the weight of the clinker. Therefore the clinker will contain 6 per cent. of ash and 94 per cent. of raw material. The hydraulic modulus of the raw material necessary to give an hydraulic modulus of the clinker of, say, 2·2 can be calculated from the following formulæ :

$$\frac{6C + 94x}{6A + 94y} = 2{\cdot}2 \; ; \qquad x + y = 97,$$

where C is the percentage of lime in the ash, $A = SiO_2 + R_2O_3$ (for the ash), x is the ratio of lime in the raw material to the calculated amount of material (excluding that lost on ignition), and 97 is the value of $CaO + SiO_2 + R_2O_3$ in the mixture calculated without loss on ignition. If it is assumed that C is 19 per cent. and A is 63·42 per cent., substitution in the formulæ gives $y = 27{\cdot}8$ and $x = 69{\cdot}2$. As a result the hydraulic modulus of the raw material must be $\frac{69{\cdot}2}{27{\cdot}8} = 2{\cdot}5$ to obtain a modulus of 2·2 in the clinker after mixture with the ash.

This method of rectification gives good results only if the homogeneity of the mixture of raw material and ash is comparable with that of the raw material itself. Analyses of clinkers burnt with fuels of high argillaceous-ash content or with calcareous ash confirm that the homogeneity required is produced with fuels the ash of which is not too argillaceous or calcareous. In the case of argillaceous ash the reduction of the hydraulic modulus and the ratios

$$\frac{SiO_2}{Al_2O_3 + Fe_2O_3} \text{ and } \frac{Al_2O_3}{Fe_2O_3}$$

correspond to parts of the clinker where a central core of alite and belite is surrounded by a crust of belite, probably due to the limited time during which the ash is in contact with the clinkering material.

The use of calcareous ash is less objectionable because, if the mixture of ash and raw material is not homogeneous, it can be observed that around the granules of clinker a crust of porous and friable substance of high lime-content forms. The crust is easily removed by friction during the rotation of the kiln and results in pulverised material of high lime-content. If the lime-content of the ash is not too great, the enrichment in lime of the clinker does not have a marked effect on the quality of the clinker since the enrichment is restricted to the surface of the materials. Characteristic amounts of the increase in the free-lime content of clinkers obtained under these conditions are from 0·26 per cent. for the ground materials to 0·23 per cent. for the exterior of the crust, 0·37 per cent. for the interior of the crust, and 1·16 per cent. for the core.

Vertical Kilns.

The clinkers produced in rotary kilns and automatic vertical kilns are examined in relation to the ash from the fuel by M. Appiano in "Il Cemento." From the determination of the free-lime content, the amount of insoluble residue, and the strength of the resulting cement, the author concludes that during burning in a rotary kiln the ashes combine with the clinker, whereas they do not do so in an automatic vertical kiln.

A report of an investigation of economy of the use of fuel in vertical kilns with compressed air is given by M. Mansuelli in "L'Industria Italiano del Cemento," and some of the conclusions relating to Portland cement stated by the author are as follows. The economy of fuel in the burning of ordinary mixtures for Portland cement is directly proportional to the degree of fineness and homogeneity of the raw materials. The best Portland cements are obtained from clinkers that are scorified to the greatest extent, a process requiring relatively long periods of burning. The influence of the size and grading of the fuel and its diffusion in the mass of the clinker is not negligible; for example the compressive strength of ordinary cement prepared with 23 per cent. by weight of coal (anthracite from Donetz, 6,854 calories per kilogramme) graded from 1 mm. down was found to be 10 per cent. to 20 per cent. greater than when prepared with 25 per cent. of similar coal graded from 5 mm. down.

Expanding Cement.

WE are informed by Monsieur Henry Lossier that he wishes to operate in Great Britain his British patent No. 647,581 relating to expanding cement, which was described in this journal for January 1947. Those interested should communicate with M. Lossier at 8 rue du Square Carpeaux, Paris 18e.

Some Views on the Action of Gypsum.

THE probable action of gypsum when mixed with Portland cement continues to be the subject of investigations, and in the following are given some views expressed in recent years.

Forms of Calcium Sulphate.

There appear to be four forms of calcium sulphate, namely, gypsum ($CaSO_4 . 2H_2O$), plaster of Paris ($CaSO_4 . \frac{1}{2}H_2O$), and the soluble and insoluble anhydrite ($CaSO_4$). The soluble form is transformed into the insoluble (a stable phase) only at temperatures between 300 deg. and 400 deg. C. According to an article in "Revue des Materiaux,"[1] in the system $CaSO_4 . H_2O$, considered between 0 deg. and 200 deg. C., the transition from gypsum to anhydrite takes place at about 42 deg. C., and from gypsum to the demi-hydrate at about 97 deg. C., the gypsum being entirely metastable between these two temperatures. The transition from the demi-hydrate to the soluble anhydrite occurs at a very high temperature which it is difficult to ascertain because of the instability of these two states.

Effect of Lime.

L. Chassevent and P. Stiglitz[2] have shown that, with artificial cements rich in lime, calcium sulphate retards the setting because it combines with the aluminate contained in the cement to give a gelatinous unstable sulpho-aluminate of one molecule of $CaSO_4$, which does not harden. With cements that do not give a concentrated solution of lime when in contact with water, calcium sulphate gradually produces needle-like crystals of stable sulpho-aluminate of three molecules of $CaSO_4$, which accelerate the setting and hardening of the cement.

R. Stratta[3] has confirmed the theory of Le Chatelier and Gallo that the crystals of gypsum in mortar are always needle-shape when the setting is complete. This investigator has also shown that the crystallisation of $CaSO_4 . 2H_2O$ is affected by the *pH* value and takes place in the ordinary manner when the *pH* value is 3.

Effect on Shrinking of Concrete.

The effects of the amount of gypsum on the tendency of concrete to shrink and crack have been investigated by G. Pickett,[4] who conducted warping tests on concrete prisms which were permitted to dry from one side only. It was found that generally there is an amount of gypsum for each type of cement which produces the least loss of weight, a different amount to produce the least shortening, and another amount for least warping. For two ordinary Portland cements the least cracking occurred with the greatest gypsum contents used. For other types of cements there was no consistent indication that the gypsum content had any effect on shrinking and cracking. Specimens wet-cured for 28 days shortened and warped less but developed greater stresses due to shrinking than specimens wet-cured for seven days. There were indications that the rate of hydration during the first few hours has an effect on the amount of shrinking during subsequent drying.

The author's tentative conclusions are as follows. Increase in the C_3A content of the cement, unless accompanied by an increase in the gypsum content, results in greater shrinking of the concrete. The addition of gypsum up to an optimum amount apparently reduces shrinking by reducing the specific surface of the cement gel formed. Cement gels formed from the hydration of cements of high C_3A content and ordinary gypsum content are of higher specific surface than those formed from cements of either low C_3A content or high C_3A content with sufficient gypsum to retard properly the early hydration. There is some indication that the rapidity with which C_3A is hydrated after the gypsum is depleted may be a factor in causing the gels of cements, the setting of which are improperly retarded, to be of high specific surface. It is also probable that gels formed from the hydration of C_3A are generally of higher specific surface than those formed from hydration of C_2S and C_3S. It is thought to be significant that the gypsum content required for least shrinking is about equal to the gypsum content required for retarding properly the early hydration.

Concrete made of cements of high alkali content dry more slowly and warp more than those made with cements of low alkali content. The higher the alkali content of the cement the greater the proportion of gypsum required for retarding properly the early hydration of a cement of given C_3A content.

The tendency to develop stresses due to shrinking during drying is reduced by increasing the gypsum content. Except for cements of low C_3A content, the reduction in stress is less than the reduction in the degree of warping, indicating probably that increasing the gypsum content decreased the plastic flow under stress.

Some of the cements used in the tests and some of the results are in agreement with the experiments made by Mr. W. Lerch,[5] reference to which was made in this journal for January, 1951, in an abstract of the report[6] of an American committee considering the optimum amount of gypsum in Portland cement.

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